09/423066

PCT/PTO 1 NOV 1999

INS A1

METHOD AND ARRANGEMENT FOR DETERMINING AT LEAST ONE DIGITAL SIGNAL VALUE FROM AN ELECTRICAL SIGNAL

The goal of the information theory established by Claude Shannon in 1948 is to develop efficient codes for encoding transmission and decoding of digital data and to optimally utilize the available information of the encoded data in the decoding insofar as possible.

INS A2 ~~[5]~~ discloses an identification of a transmission channel for the transmission of digital data.

Two types of decoding are distinguished in the decoding of digital data:

- in what is referred to as hard decision decoding, a received signal infested with noise by the transmission over a channel is decoded into a sequence of digital data, whereby only the digital value of the respectively received signal is classified; and
- in what is referred to as soft decision decoding, an ~~A~~ a posteriori probability for the value to be classified is additionally determined for each information character to be decoded. Such a posteriori probabilities are also referred to as soft outputs and form a criterion for the dependability of the decoding.

Soft decision decoding shall be considered below.

Fundamentals of what are referred to as block codes are known from ~~[2]~~. INS A3

It is known from ~~[3]~~ A4 to implement a soft decision decoding for a binary, linear block code.

The method from [3] for exact calculation of digital signal values from an electrical signal shall be explained below upon employment of what is referred to as log-likelihood algebra.

It is assumed below that the output of a source encoder of a first arrangement is composed of a sequence of digital, preferably binary signal words that are referred to below as code words. The finite ~~plurality~~ number of stochastically independent random variables,

$$U_i\colon \Omega \rightarrow \{\pm 1\}, \quad i = 1,\ldots,m, m \in N \tag{1}$$

is considered, these being defined on a likelihood space (Ω, S, P). S references a σ-algebra, i.e. the set of events for which a likelihood is defined. P references a likelihood criterion ($P{:}S \rightarrow [0, 1]$). Under the assumption that the inequalities

$$0 < P(\{\omega \in \Omega;\ U_i(\omega) = 01\}) < 1, \quad i = 1,\ldots,m \tag{2}$$

are met, what are referred to as L-values ~~Lj-values~~ of the random variables U_i are defined by

$$L(U_i) := \ln\left(\frac{P(\{\omega \in \Omega;\ U_i(\omega) = +1\})}{P(\{\omega \in \Omega;\ U_i(\omega) = -1\})}\right), \quad i = 1,\ldots,m \tag{3}$$

Code words $\underline{u}$ have the following structure:

$\underline{u} \in \{\pm 1\}^k$.

It is thereby assumed for each code word ~~words~~ $\underline{u}$ that each digital value u_i, $i=1\ldots k$ of the code word $\underline{u}$ assumes a first value (logical "0" or logical "+1") or a second value (logical "1" or logical "-1") with the same likelihood. Since one must count on disturbances in the transmission of messages that can falsify the messages, a further encoding step, channel encoding, is implemented.

As described in ~~[1]~~, redundancy is intentionally added to the incoming code words $\underline{u}$ in the channel encoding in order to be able to correct possible transmission errors and, thus, assure a high transmission dependability. It is assumed below that a channel code word $\underline{c} \in \{\pm 1\}^n$, $n > k$, $n \in N$, is allocated to each code word $\underline{u} \in \{\pm 1\}^k$. The output of the means for channel encoding is thus composed of code words having the form $\underline{c} \in \{\pm 1\}^n$.

The channel code words are transmitted from a transmission means to a reception means via a physical channel, for example a

subscriber line, coaxial cable, mobile radio telephone, directional radio, etc.

Since the physical channel can often not transmit discrete symbols but only time-continuous signals (i.e., specific functions s: $\Re \rightarrow \Re$), a modulator is often provided with which a function which is suitable for the transmission via the physical channel, is allocated to the channel code word c. An important characteristic quantity of the transmitted electrical signal is the average energy E_b that is employed for the transmission of an information bit of the channel code word c.

Since a disturbance can occur in the transmission of an electrical signal via a physical channel, an electrical signal $\tilde{s} : \Re \rightarrow \Re$, that is modified compared to the transmitted electrical signal is received.

The disturbance is described with methods of stochastic signal theory. A characteristic quantity of the disturbance is the known single-side noise power density N_0 that is determined by the channel. After a potential demodulation of the received electrical signal $\tilde{s}$, a vector $y \in \Re^n$ is present instead of the code ~~words~~ word c. The absolute amount of each component of the vector y is thereby interpreted as dependability information for the corresponding operational sign of the component in the framework of the soft decision decoding.

The channel decoding then has the job - upon employment of the received, potentially demodulated electrical signal $\tilde{s}$ that is ultimately available as vector y - of reconstructing the code word u that was originally present.

It is standard to model the physical channel and the noise properties thereof. A model frequently employed for this purpose is what is referred to as the invariant AWGN channel (additive Gaussian white noise). When a modulator and a demodulator are present the totality of modulator, physical channel and demodulator is referred to below as the channel in this model. Given the AWGN channel, it is assumed that the output of the channel encoder, i.e. the channel code word c is additively superimposed by an $N\left(0, \frac{N_0 n}{2E_b k}, I_n\right)$ - normally distributed random variable,

whereby I_n references the n-dimensional unit matrix. The quotient $\frac{N_0}{E_b}$ is known and is also referred to as signal-to-noise ratio.

By complete induction for m, it can be shown on the basis of the stochastic independence of the random variables U_1 U_m ~~$U_1, \ldots, U_m$~~ that the following is valid for the L-value of the chained random variables $U_1 \oplus \ldots \oplus U_m$ ($\oplus$ ~~($\oplus$)~~ references an exclusive-OR operation):

$$U_1 \oplus U_2 \oplus \ldots U_m: \Omega \rightarrow \{\pm 1\},\ \omega \rightarrow U_1(\omega) \oplus U_2(\omega) \oplus \ldots U_m(\omega) \tag{4}$$

and

$$L(U_1 \oplus U_2 \oplus \ldots U_m) = \ln\left(\frac{1 + \prod_{i=1}^{m} \frac{\exp(L(U_i)) - 1}{\exp(L(U_i)) + 1}}{1 - \prod_{i=1}^{m} \frac{\exp(L(U_i)) - 1}{\exp(L(U_i)) + 1}}\right) \tag{5}$$

The following initial situation derives for the method known from ~~[3]~~: natural number k, n and sets $J_{k+1}, \ldots, J_n \subseteq \{1, \ldots, k\}$, that describe the properties of the channel encoder are established, as is the non-negative, real number $\frac{N_0}{E_b}$. The number ~~plurality~~ of digital values of the code word $\underline{u}$ is referenced k. The number ~~plurality~~ of digital values of the channel code word $\underline{c} \in \{\pm 1\}^n$, is referenced n, with $n > k$. The n-k digital values that are attached to the code words $\underline{u}$ in the formation of the channel code word $\underline{c}$, which are also referred to as check bits, are characterized by $J_{k+1}, \ldots, J_n \subseteq \{1, \ldots, k\}$.

Further, a likelihood space (Ω, S, P) and a small-dimensional random variable C

$$C: ~~\in~~ \Omega \rightarrow \{\pm 1\}^n \tag{6}$$

having the following properties is established:

- components

$$C_1,\ldots,C_k:\Omega \rightarrow \{\pm 1\} \tag{7}$$

of the n-dimensional random variable $\underline{C}$ are stochastically independent and

$$P(\omega \in \Omega; C_i(\omega) = -1) = P(\omega \in \Omega; C_i(\omega) = +1) = \frac{1}{2} \tag{8}$$

applies to all $i=1,\ldots, k$.

- the following applies to each $i \in \{k + 1, \ldots ,n\}$ and to all $\omega \in \Omega$:

$$C_i(\omega) = \bigoplus_{j \in J_i} C_j(\omega) \tag{9}$$

The digital values that are formed by the channel encoding, i.e. the channel code words $\underline{c}$, are interpreted as realization of the random variables $\underline{C}$.

The output $\tilde{u}$ of the channel decoder to be reconstructed, which is referred to below as a set of digital signal values, are the corresponding realization of the random variables

$$U: \Omega \rightarrow \{\pm 1\}^k,\ \omega \rightarrow (C_1(\omega),\ldots, C_k(\omega))^T \tag{10}.$$

The output

$$\underline{y} \in \Re^n \tag{11}$$

of the unit for demodulation or, ~~respectively~~, the vector that describes the electrical signal and for which the decoding ensues is interpreted as realization of the random variables

$$\underline{Y}: \rightarrow \Re^n,\ \omega \rightarrow \underline{C}(\omega) + Z(\omega) \tag{12}$$

whereby $Z: \Omega \rightarrow \Re^n$ is $N\left(0, \frac{N_0 n}{2E_b k} I_n\right)$ - normally distributed random variable that is stochastically independent of the n-dimensional random variable $\underline{C}$. The code word $\tilde{u}$ is reconstructed based on the vector $\underline{y}$ describing the received electrical signal.

In order to reconstruct the individual digital signal values, the distribution of the random variables C is investigated under the condition that the vector $\underline{y}$ describing the electrical signal was received.

The likelihoods induced by this distribution are referred to as ~~A~~ a posteriori likelihoods.

The following quantities are considered for each $\epsilon > 0$:

$$L_\varepsilon(U_i|\underline{y}) := \ln\left(\frac{P\left(\{\omega \in \Omega; U_i(\omega) = +1\} \middle| \{\omega \in \Omega; \underline{Y}(\omega) \in M_{\underline{y},\varepsilon}\}\right)}{P\left(\{\omega \in \Omega; U_i(\omega) = -1\} \middle| \{\omega \in \Omega; \underline{Y}(\omega) \in M_{\underline{y},\varepsilon}\}\right)}\right) = \ln\left(\frac{\sum\limits_{\substack{\underline{v} \in C \\ v_i = +1}} P\left(\{\omega \in \Omega; \underline{C}(\omega) = \underline{v}\} \middle| \{\omega \in \Omega; \underline{Y}(\omega) \in M_{\underline{y},\varepsilon}\}\right)}{\sum\limits_{\substack{\underline{v} \in C \\ v_i = -1}} P\left(\{\omega \in \Omega; \underline{C}(\omega) = \underline{v}\} \middle| \{\omega \in \Omega; \underline{Y}(\omega) \in M_{\underline{y},\varepsilon}\}\right)}\right) \quad (13).$$

for i = 1,...,k, whereby

$$M_{y,\epsilon} := [y_1, y_1 + \epsilon] \times \ldots \times [y_n, y_n + \epsilon] \quad (14)$$

and C references the set of all channel code words $\underline{c}$.

The following derives by employing the theorem of Bayes:

$$L_\varepsilon(U_i|\underline{y}) := \ln\left(\frac{\sum\limits_{\substack{\underline{v}\in C\\ v_i=+1}} P\left(\left\{\omega\in\Omega;\ \underline{Y}(\omega)\in M_{\underline{y},\varepsilon}\right\}\middle|\left\{\omega\in\Omega;\ \underline{C}(\omega)=\underline{v}\right\}\right)}{\sum\limits_{\substack{\underline{v}\in C\\ v_i=-1}} P\left(\left\{\omega\in\Omega;\ \underline{Y}(\omega)\in M_{\underline{y},\varepsilon}\right\}\middle|\left\{\omega\in\Omega;\ \underline{C}(\omega)=\underline{v}\right\}\right)}\right)$$

$$= \ln\left(\frac{\sum\limits_{\substack{\underline{v}\in C\\ v_i=+1}} \int\limits_{M_{\underline{y},\varepsilon}} \exp\left(-\frac{(\underline{x}-\underline{v})^T(\underline{x}-\underline{v})}{\frac{N_0 n}{E_b k}}\right)dx}{\sum\limits_{\substack{\underline{v}\in C\\ v_i=-1}} \int\limits_{M_{\underline{y},\varepsilon}} \exp\left(-\frac{(\underline{x}-\underline{v})^T(\underline{x}-\underline{v})}{\frac{N_0 n}{E_b k}}\right)dx}\right) \qquad (15).$$

When the boundary transition of (14) for $\varepsilon \rightarrow 0$ is considered by multiple employment of the rule of De L'Hospital, then the ~~software~~ soft outputs $L(U_i|\underline{y})$ are obtained for each character according to the following rule:

$$L(U_i|\underline{y}) = \ln\left(\frac{\sum\limits_{\substack{\underline{v}\in C\\ v_i=+1}} \exp\left(-\frac{(\underline{y}-\underline{v})^T(\underline{y}-\underline{v})}{\frac{N_0 n}{E_b k}}\right)}{\sum\limits_{\substack{\underline{v}\in C\\ v_i=-1}} \exp\left(-\frac{(\underline{y}-\underline{v})^T(\underline{y}-\underline{v})}{\frac{N_0 n}{E_b k}}\right)}\right) \qquad (16).$$

The soft outputs that, on the one hand, usually contain an operational sign information and a dependability information (absolute amount of the soft output), are referred to below as dependability degree.

In a completely analogous way, the following is obtained for i = k + 1, ..., n:

$$L\left(\underset{j \in J_i}{\oplus} U_j \middle| \underline{y}\right) = \ln\left(\frac{\sum\limits_{\substack{\underline{v} \in C \\ \nu_i = +1}} \exp\left(-\frac{\left(\underline{y}-\underline{v}\right)^T\left(\underline{y}-\underline{v}\right)}{\frac{N_0 n}{E_b k}}\right)}{\sum\limits_{\substack{\underline{v} \in C \\ \nu_i = -1}} \exp\left(-\frac{\left(\underline{y}-\underline{v}\right)^T\left(\underline{y}-\underline{v}\right)}{\frac{N_0 n}{E_b k}}\right)}\right) \quad (17).$$

The decoding in the known method ensues such that, when the dependability degree exhibits a value greater than 0, the i^{th} component u_i of the code word ũ to be reconstructed is reconstructed with the second value (logical "1" or logical "-1"). For a value of the dependability degree less than 0, the first value (logical "0" or logical "+1") is allocated to the digital signal value. One can arbitrarily decide in favor of the first or the second value for ~~the~~ a value of the dependability degree ~~equals~~ equal to 0. The absolute amount of the dependability degree is a criterion for the dependability of the above decision rules. The reconstruction is all the more dependable the higher the absolute amount.

What is disadvantageous about this known method is the outlay for computer-assisted determination of the dependability degree. The determination of the dependability degree generally requires an outlay for additions that is proportional to min (2^k, 2^{n-k}). The direct calculation of the dependability degrees and the determination of the digital values dependent on the dependability degrees is thus often not numerically realizable. Approximately 10^{20} additions would be required for what is referred to as the BCH (255, 191) - Code (see ~~[2]~~ A47 for the calculation of the 191 dependability degrees and digital signal values.

INS A8 The ~~invention is thus based on the problem of specifying~~ a method and an arrangement for determining at least one digital signal value from an electrical signal that contains signal information and redundancy information for the signal information determined from the signal

information, whereby a simplified determination compared to the known method is possible.

BS A10

The problem is solved by the method according to patent claim 1 as well as by the arrangement according to patent claim 10.

a dependability degree

~~Given the method according to patent claim 1, a dependability measure~~ for forming the signal value is approximated from the electrical signal and the signal value is determined dependent on the dependability degree.

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~~The arrangement according to patent claim 10 contains a computer unit~~ that is configured such that a dependability degree for forming the signal value is approximated from the electrical signal and such that the signal value is determined dependent on the dependability degree.

INS A12

Given the method according to patent claim 1 and given the arrangement according to patent claim 10, further, the approximation of the dependability degree ~~respectively~~ ensues such that a target function is optimized, whereby the target function contains a model of a transmission channel over which the electrical signal was transmitted.

Due to the approximation of the dependability degree that had to be exactly determined hitherto and dependent whereon the signal value is determined, a considerable simplification is achieved in the determination of the digital signal value. This leads to a substantially faster implementation of the method by a computer or, ~~respectively,~~ to considerable saving of costs for the realization of the arrangement for determining the digital signal value. A numerical solution of the soft decision decoding thus often becomes possible at all for the first time.

The present invention can be clearly seen therein that the dependability degree that was hitherto only exactly calculated is approximated.

Due to the approximation of the a dependability degree by the optimization of the target function, an extremely simple and, thus, quickly implemented possibility is recited that even takes the properties of the transmission channel and, thus, the noise properties of the disturbed signal into consideration.

The minimization of the target function that contains the properties of the channel in the form of the model as approximation criterion leads thereto that the efficiency of the method or, ~~respectively,~~ of the arrangement is substantially improved. As a result of this development, a considerable reduction of the

signal-to-noise ratio $\frac{N_0}{E_b}$ is achieved compared to known methods given the same bit error probability in the determination of the digital signal values. The improvement of the signal-to-noise ratio amounts to up to approximately 3 dB dependent on the channel encoding employed, which would correspond to the maximum improvement that could be theoretically achieved.

A saving of 1 dB, for example, can already lead to a cost saving of approximately 70 million U. S. dollars in the construction of ~~the~~ a space probes given radio transmission from space probes. Considerable cost ~~saving~~ savings scale is thus possible for the control center as well when the decoding ensues according to this ~~development or, respectively~~ embodiment or when, the arrangement according to ~~the development~~ one embodiment is configured such that the approximation ensues by optimizing a target function that contains a model of the transmission channel.

~~Advantageous developments of the invention derive from the dependent claims.~~

In ~~a development~~ an embodiment both of the method as well as of the arrangement, further, it is advantageous that the target function is formed according to the following rule:

$$f = \sum_{i=1}^{k}\left(\beta_i - \frac{4E_b k}{N_0 n} y_i\right)^2 + \sum_{i=k+1}^{n}\left(\ln\left(\frac{1 + \prod_{j\in J_i}\frac{\exp(\beta_j) - 1}{\exp(\beta_j) + 1}}{1 - \prod_{j\in J_i}\frac{\exp(\beta_j) - 1}{\exp(\beta_j) + 1}}\right) - \frac{4E_b k}{N_0 n} y_i\right)^2 .$$

A modified scaling or a slight modification and neglecting of some values in the target function as well as the degree of the counter function

(degree of the target function) is thereby not critical and can be arbitrarily varied.

This target function indicates a model for the transmission channel in which the assumed ~~the~~ model properties of the transmission channel ~~is~~ ~~[sic]~~ taken into consideration, this supplying extremely good results in the determination of the signal values after the optimization given optimization of the target function, for example, a minimization of the error function.

It is also advantageous to subject the target function to a global minimization since the information contained in the electrical signal is optimally utilized in the framework of the optimization due to this procedure and, thus, is also optimally utilized in the determination of the signal value.

It is also advantageous that the electrical signal is a radio signal and, thus, the arrangement is a radio transmission system with an inventive arrangement, since the method enables substantial savings specifically in the area of radio transmission, particularly in the transmission of radio signals with a space probe.

The method can also be advantageously utilized in the archiving and reconstruction of ~~archive,~~ archived stored digital data that ~~[...]~~ is contained in a storage medium (for example, magnetic tape store, hard disc store, etc.), since an improved signal-to-noise ratio is also of considerable significance in this application.

INS A13

Exemplary embodiments of the invention are described in the Figures, these being explained in greater detail below.

Fig. 1 a flow chart wherein the method, which is implemented in a computer unit, is shown in terms of its individual method steps;

Fig. 2 a block circuit diagram, whereby the sending, the transmission and the reception of the electrical signal is shown;

Fig. 3 a sketch of a radio transmission system;

Fig. 4 a sketch of an archiving system for archiving digital data.

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Fig. 2 symbolically shows a source ~~201 proceeding from which~~ a ~~message N is to be~~ transmitted to a sink sync 209.

The message N to be transmitted is supplied to a source coder 202, where it is compressed such that, although no information is lost, redundancy information superfluous for the decoding of the message is is eliminated and, thus, the required transmission capacity is reduced.

The output of the source coder 202 is the code word $\underline{u} \in \{\pm 1\}^k$ that is composed of a sequence of digital values. It is thereby assumed for each code word $\underline{u}$ that each value u_i, $i = 1,...k$ of the code words $\underline{u}$ assumes a first value (logical "0" or logical "+1") or, ~~respectively,~~ a second value (logical "1" or logical "-1") with the same probability.

The code word $\underline{u}$ is supplied to a unit for channel encoding 203 wherein a channel encoding of the code word $\underline{u}$ ensues. In the channel encoding, redundancy information is intentionally attached to the code word $\underline{u}$ in order to be able to correct or at least recognize transmission errors that possibly arise during the transmission and, thus, to achieve a high transmission dependability.

It is assumed below that the channel encoding allocates a channel code word $\underline{c} \in \{\pm 1\}^n$ to each code word $\underline{u} \in \{\pm 1\}^k$. The output of the unit for channel encoding 203 is thus composed of the channel code word $\underline{c} \in \{\pm 1\}^n$.

The channel code word $\underline{c} \in \{\pm 1\}^n$ is supplied to a unit for modulation 204 of the channel code word $\underline{c}$. In the modulation, a function s: $\Re \rightarrow \Re$ suitable for the transmission over a physical channel 205 is allocated to the channel code word $\underline{c}$.

The signal to be transmitted thus contains both signal information, i.e. the channel code word $\underline{c}$, as well as redundancy information determined from the signal information, i.e. additionally contains what are referred to as check values. The modulated signal s is transmitted via the physical channel 205 to a receiver unit 211. A disturbance 210 that falsifies the modulated signal s often occurs during the transmission over the

physical channel 205. A modified, modulated signal $\tilde{\underline{s}}$ is thus adjacent at the receiver unit, this being supplied to the unit for demodulation 206.

A demodulation of the modified, modulated signal $\tilde{\underline{s}}$ ensues in the unit for demodulation 206. The output of the demodulation is a vector $\underline{y} \in \Re^n$ referred to below as electrical signal that describes the digital, demodulated, modified signal $\tilde{\underline{s}}$.

During the course of further considerations, the model of what is referred to as the AWGN channel is employed for modeling the physical channel 205, as was set forth above. For simplification, both the unit for modulation 204 as well as the unit for demodulation 206 of the transmitter 200 or, respectively, of the receiver 211 is also considered in the model of the transmission channel.

The electrical signal $\underline{y}$ is subjected to a channel decoding in a unit for channel decoding 207. Vector components y_i of the electrical signal $\underline{y}$ contain both an operational sign information as well as an amount information.

The amount information is respectively the absolute value of the vector components y_i that is also referred to as dependability information for the corresponding operational sign of the vector components y_i.

The job in the channel decoding is to implement what is referred to as a soft decision decoding. This means that, first, a reconstructed code word

$\underline{\tilde{u}}$ is reconstructed and, further, a dependability information is determined for each component, this describing the decision made for reconstruction of a component $\tilde{u}_i$ of the reconstructed code word $\underline{\tilde{u}}$. A component $\tilde{u}_i$ of the reconstructed code word $\underline{\tilde{u}}$ is referred to below as digital signal value.

The reconstructed code word $\underline{\tilde{u}}$, i.e. at least one digital signal value, is supplied to a unit for source decoding 208 wherein a source decoding ensues. Finally, the decoded signal is supplied to the ~~sink~~ SYNC 209.

The channel decoding 207 is described in greater detail in Fig. 1 in the form of a flow chart.

In a first Step 101, a target function f, which contains a non-linear regression model of the transmission channel 204, 205, 206, is optimized.

The non-linear regression model is derived below for illustration.

From the following ~~above-described~~ rule (16) for exact determination of the dependability degree,

$$L\left(U_i \middle| \underline{y}\right) = \ln\left(\frac{\sum\limits_{\substack{\underline{v} \in C \\ \nu_i = +1}} \exp\left(-\dfrac{\left(\underline{y} - \underline{v}\right)^T\left(\underline{y} - \underline{v}\right)}{\frac{N_0 n}{E_b k}}\right)}{\sum\limits_{\substack{\underline{v} \in C \\ \nu_i = -1}} \exp\left(-\dfrac{\left(\underline{y} - \underline{v}\right)^T\left(\underline{y} - \underline{v}\right)}{\frac{N_0 n}{E_b k}}\right)}\right) \qquad (16)$$

wherein

- N_0 indicates a single-sided noise power density,
- n indicates a number ~~plurality~~ of digital signal values contained in the signal,
- E_b denotes an average signal energy for one of the k signal values, i.e. of the information bits,
- k denotes a number ~~plurality~~ of digital signal values contained in the electrical signal,
- $\underline{y}$ denotes a vector from ~~gothic~~ $\Re^n$ that describes the signal,
- C denotes the set of all channel code words,
- $\underline{C}$ denotes an n-dimensional random quantity for describing the signal value,
- $\underline{v}$ denotes a vector from C,
- i denotes an index for unambiguous identification of the signal value v_i,
- U_i denotes a random variable of the signal value v_i,
- $L(U_i|\underline{y})$ denotes the dependability degree,
- J_i denotes a set of digital values of the redundancy information, and
- j denotes a further index,

the factor in the numerator,

$$\exp\left(-\frac{(y_i - 1)^2}{\frac{N_0 n}{E_b k}}\right) \tag{18}$$

and the factor in the denominator

$$\exp\left(-\frac{(y_i + 1)^2}{\frac{N_0 n}{E_b k}}\right) \tag{19}$$

can be bracketed out.

After the bracketing, the following rule derives for all i = 1,...,k with corresponding factors τ_i that are now no longer dependent on the components y_i of the electrical signal:

$$L(U_i|\underline{y}) = \ln \frac{\exp\left(-\frac{(y_i - 1)^2}{\frac{N_0 n}{E_b k}}\right)}{\exp\left(-\frac{(y_i + 1)^2}{\frac{N_0 n}{E_b k}}\right)} + \tau_i = \frac{4E_b k}{N_0 n} y_i + \tau_i \tag{20}.$$

The following is valid for i = k + 1, ..., n:

$$L\left(\bigoplus_{j \in J_i} U_j|\underline{y}\right) = \frac{4E_b k}{N_0 n} y_i + \tau_i \tag{21}.$$

If the physical channel 205 were not disturbed, then the observation of the respective components y_i of the electrical signal would suffice for i = 1, ..., k in order to determine the distribution of U_i under the condition that the random variable $\underline{Y}$ assumes the value $\underline{y}$. All factors $\tau_i = 0$ would thus be the case. The situation is analogous for i = k + 1, ...,n with the

distribution $\bigoplus_{j \in J_i} U_j$ under the condition that the random variable $\underline{Y}$ assumes the value $\underline{y}$. In this case, too, all factors $t_i = 0$ would apply. The absolute values of the factors $\tau_1, \ldots \tau_n$ are thus a measure for the channel disturbance.

Under the condition that the signal $\underline{y}$ was received, the stochastic independence of the variables $U_1, \ldots, U_k$ is lost.

Therefore valid for $i = k + 1, \ldots, n$ with corresponding error factor ρ_i:

$$L\left(\bigoplus_{j \in J_i} U_j \middle| \underline{y}\right) = \ln\left(\frac{1 + \prod_{j \in J_i} \frac{\exp(L(U_j|\underline{y})) - 1}{\exp(L(U_j|\underline{y})) + 1}}{1 - \prod_{j \in J_i} \frac{\exp(L(U_j|\underline{y})) - 1}{\exp(L(U_j|\underline{y})) + 1}}\right) + \rho_i \qquad (22).$$

It is also obvious for the error factors $\rho_{k+1}, \ldots, \rho_n$ that all $\rho_{k+1}, \ldots, \rho_n$ can be set equal to 0 when the physical channel is not disturbed.

The following rule derives overall:

$$\frac{4E_b k}{N_0 n}\underline{y} = \begin{pmatrix} L(U_1|\underline{y}) \\ \vdots \\ L(U_k|\underline{y}) \\ \ln\left(\frac{1 + \prod_{j \in J_{k+1}} \frac{\exp(L(U_j|\underline{y})) - 1}{\exp(L(U_j|\underline{y})) + 1}}{1 - \prod_{j \in J_{k+1}} \frac{\exp(L(U_j|\underline{y})) - 1}{\exp(L(U_j|\underline{y})) + 1}}\right) \\ \vdots \\ \ln\left(\frac{1 + \prod_{j \in J_n} \frac{\exp(L(U_j|\underline{y})) - 1}{\exp(L(U_j|\underline{y})) + 1}}{1 - \prod_{j \in J_n} \frac{\exp(L(U_j|\underline{y})) - 1}{\exp(L(U_j|\underline{y})) + 1}}\right) \end{pmatrix} - \begin{pmatrix} \tau_1 \\ \vdots \\ \tau_k \\ \tau_{k+1} - \rho_{k+1} \\ \vdots \\ \tau_n - \rho_n \end{pmatrix} \qquad (23).$$

When the values

$$\begin{array}{ll} \text{for } i = 1, \ldots, k & L(U_i|\underline{y}) = \beta_i; \quad -\tau_i = e_i \\ \text{for } i = k+1, \ldots, n & \rho_i - \tau_i = e_i \end{array} \tag{24}$$

are replaced, then the following non-linear regression problem derives therefrom:

$$\frac{4E_b k}{N_0 n}\underline{y} = \begin{pmatrix} \beta_1 \\ \vdots \\ \beta_k \\ \ln\left(\dfrac{1 + \prod\limits_{j \in J_{k+1}} \dfrac{\exp(\beta_j) - 1}{\exp(\beta_j) + 1}}{1 - \prod\limits_{j \in J_{k+1}} \dfrac{\exp(\beta_j) - 1}{\exp(\beta_j) + 1}}\right) \\ \vdots \\ \ln\left(\dfrac{1 + \prod\limits_{j \in J_n} \dfrac{\exp(\beta_j) - 1}{\exp(\beta_j) + 1}}{1 - \prod\limits_{j \in J_n} \dfrac{\exp(\beta_j) - 1}{\exp(\beta_j) + 1}}\right) \end{pmatrix} + \underline{e} \tag{25}$$

Since an error vector $\underline{e}$ is equal to the 0 vector when no disturbance of the physical channel is established and due to the stochastic model of the channel disturbance, it is assumed that the error vector $\underline{e}$ is a realization of a random variable $E: \Omega \Rightarrow \Re^n$ with anticipation value E(E = 0). The dependability degrees are thus approximated by minimization of the influence of the channel disturbance.

Respectively one dependability measure serves for the reconstruction of a respective digital signal value.

The non-linear regression problem is formulated and solved by a target function f when the target f is optimized, minimized in this case.

The target function f is formed according to the following rule:

$$\min\left\{\underline{e}(\beta)^{T}\underline{e}(\beta)\right\} = \min\{f\}$$

with

$$f = \sum_{i=1}^{k}\left(\beta_i - \frac{4E_b k}{N_0 n} y_i\right)^2 + \sum_{i=k+1}^{n}\left(\ln\left(\frac{1 + \prod\limits_{j\in J_i}\frac{\exp(\beta_j)-1}{\exp(\beta_j)+1}}{1 - \prod\limits_{j\in J_i}\frac{\exp(\beta_j)-1}{\exp(\beta_j)+1}}\right) - \frac{4E_b k}{N_0 n} y_i\right)^2 \qquad (26).$$

The solution of the non-linear regression problem ensues by minimization of the target function f.

A method for global minimization that is known from ~~[4]~~ is employed for the minimization of the target function f.

The target function f is ~~not~~ generally not convex and it is therefore advantageous to utilize an algorithm for global minimization for the minimization of the target function, because it is possible in this way to optimally utilize the given information in the sense of information theory.

A respective dependability degree is ~~approximate~~ approximated (Step 102) for the components y_i of the electrical signal $\underline{y}$ upon employment of a neural network whose structure ~~derives~~ is derived on the basis of the determined parameters of the optimized target function f.

In a last step 103, the digital signal value or, ~~respectively~~, the digital signal ~~values~~ value $\tilde{u}_i$ is determined from the electrical signal $\underline{y}$ dependent on the dependability degree. The operational sign information of the respective dependability degree is thereby employed as a criterion for the allocation of the first or, ~~respectively~~, of the second value to the digital signal value $\tilde{u}_i$.

When the dependability degree comprises a value greater than 0, then the second value (logical "1" or logical "-1") is allocated to the digital

signal value $\tilde{u}_i$ and, when the dependability degree exhibits a value smaller then 0, then the first value (logical "0" or, ~~respectively~~, logical "+1") is allocated to the digital signal value $\tilde{u}_i$.

This is implemented for all digital signal values $\tilde{u}_i$ to be reconstructed whose reconstruction is desired.

The arrangement for channel decoding 207 is configured such that the above-described method is implemented. This can ensue by programming a computer unit or can also ensue with an electrical circuit adapted to the method.

A few alternatives and generalizations of the above-described method or, ~~respectively,~~ of the arrangement are disclosed below:

It is not necessary to implement a global minimization of the target function. The minimization can likewise ensue with a method for local minimization, for example with what is referred to as the BFGS method (Broyden, Fletcher, Goldfarb, Shanno method). Further, the minimization of the target function is not limited to the method described in ~~[4].~~ Further methods for minimization can likewise be utilized.

It is also not necessary that a quadratic norm is minimized as target function; any arbitrary norm of the vector e (β) can generally be utilized.

Fig. 3 shows a radio transmission system that contains an arrangement having the above-described features. A transmission means 301, preferably a space probe, transmits a radio signal 303 via a physical channel 205, in this case through the air. The radio signal 303 is received via an antenna 302 of the receiver arrangement 305 and is supplied as electrical signal to the arrangement 304 that contains the means for demodulation 206, the means for channel decoding 207 as well as the means for source decoding 208.

Fig. 4 shows a system 403 for the reconstruction of archived digital data. Digital data ~~are~~ is archived in ~~a storage~~ memory 401, for example, a magnetic store (magnetic band store, hard disk store, etc.). In the reconstruction, the above-described method for reconstruction of the at least one digital signal value $\tilde{u}_i$ from the electrical signal which, in this case, describes

digital signals read out from the memory 401 can be implemented upon employment of an arrangement having the means for channel decoding 207.

It is clear that the invention can be seen therein that the dependability degree that was hitherto only exactly calculated is approximated.

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